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Tanaka

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(54) **PHYSICAL QUANTITY SENSOR AND ELECTRONIC APPARATUS**

(71) Applicant: **Seiko Epson Corporation**, Tokyo (JP)

(72) Inventor: **Satoru Tanaka**, Chino (JP)

(73) Assignee: **Seiko Epson Corporation** (JP)

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G01P 1/00	(2006.01)
G01P 15/08	(2006.01)

(52) **U.S. Cl.**

CPC ***G01P 1/003*** (2013.01); ***G01P 15/0802*** (2013.01); ***G01P 15/125*** (2013.01); *G01P 2015/0882* (2013.01)

(58) **Field of Classification Search**

CPC G01P 15/125; G01P 2015/0882
USPC 73/514.13, 514.32
See application file for complete search history.

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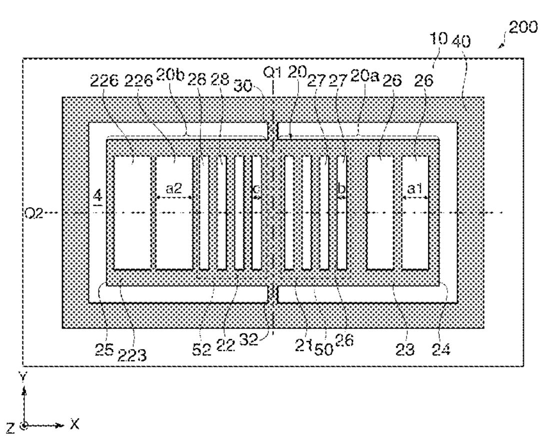
Primary Examiner — John Chapman, Jr.

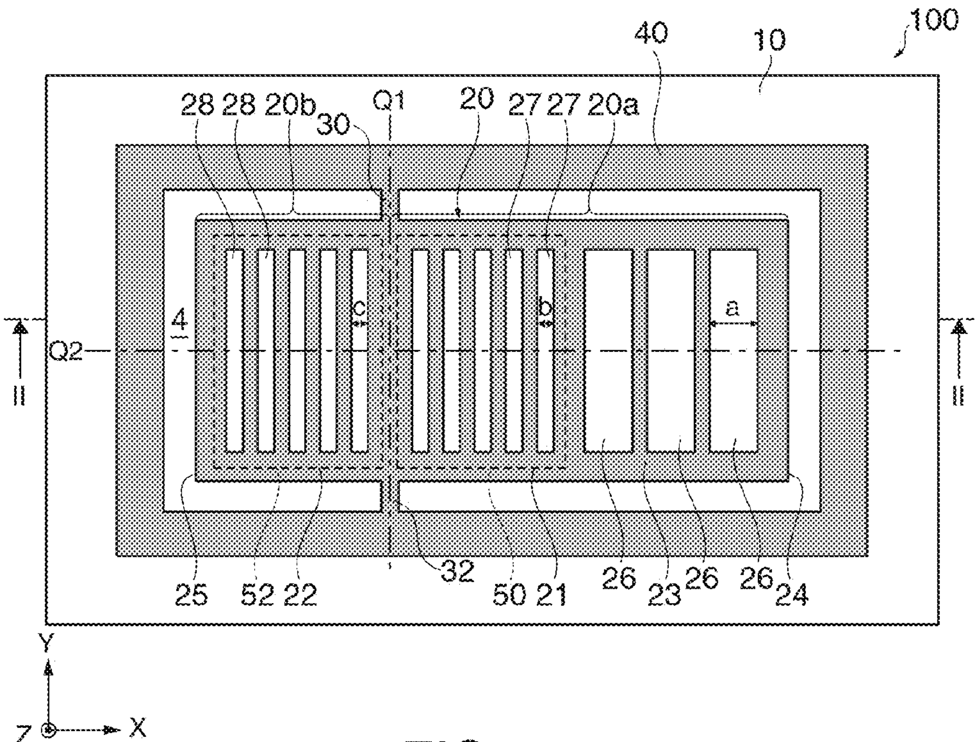
(74) *Attorney, Agent, or Firm* — Harness, Dickey & Pierce, P.L.C.

(57) **ABSTRACT**

A physical quantity sensor includes: a substrate; a movable body including, with a first axis as a boundary, a first movable electrode portion disposed in a first region, a second movable electrode portion disposed in a second region, and a damping adjusting portion disposed in at least one of the first region and the second region; beam portions supporting the movable body; a first fixed electrode portion; and a second fixed electrode portion. A first through-hole is disposed in the damping adjusting portion. Second through-holes are disposed in the movable electrode portions. The area of a region where the first movable electrode portion overlaps with the first fixed electrode portion is the same as the area of a region where the second movable electrode portion overlaps with the second fixed electrode portion. The width of the first through-hole is greater than the widths of the second through-holes.

4 Claims, 6 Drawing Sheets

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40
10
28 28 20b
30
Q1
20 27 27 20a
c
b
a
4
Q2
II
II
25
52 22
32
50 21
26
23
26
26
24
Y
Z
X

FIG. 1

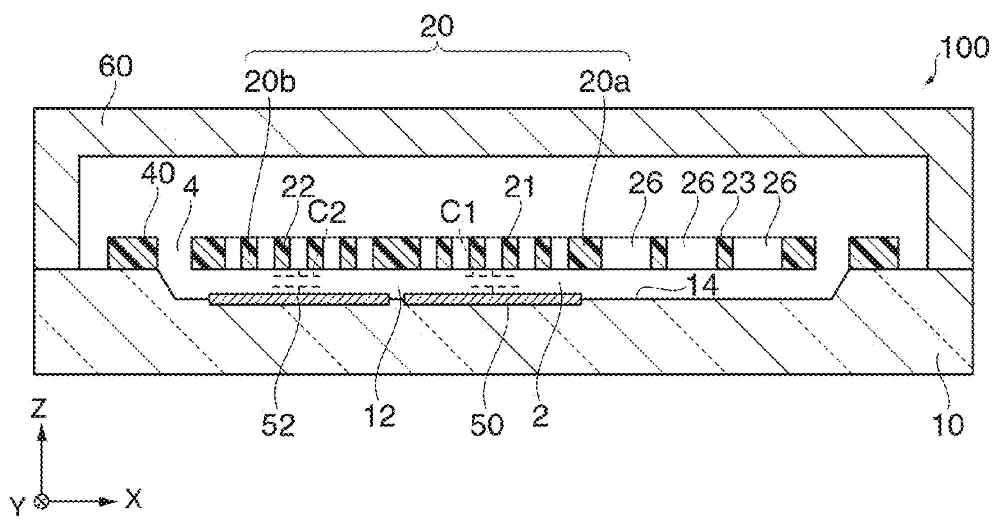

20
100
60
20b
20a
40
4
22
C2
C1
21
26 26 23 26
14
52
12
50
2
10
Z
Y
X

FIG. 2

FIG. 3

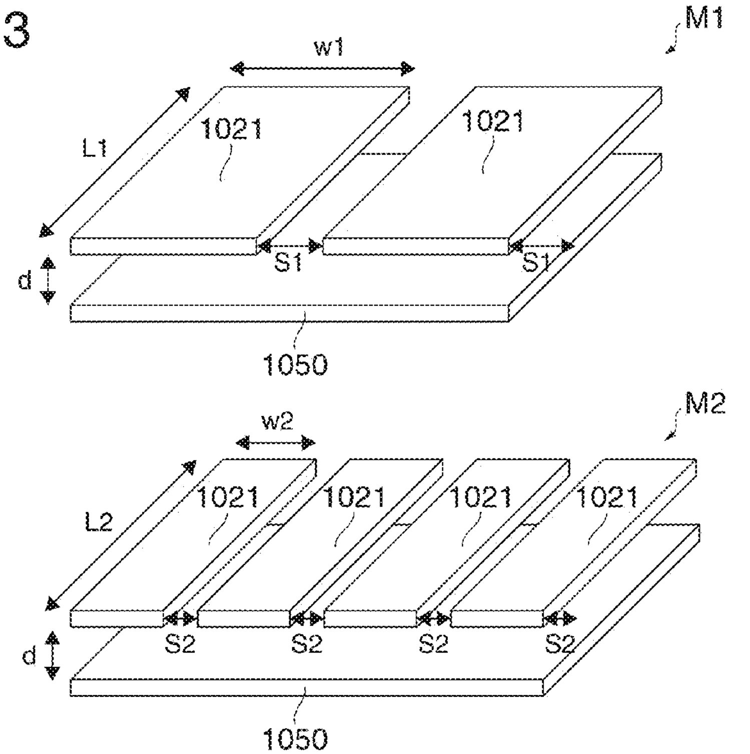


FIG. 4

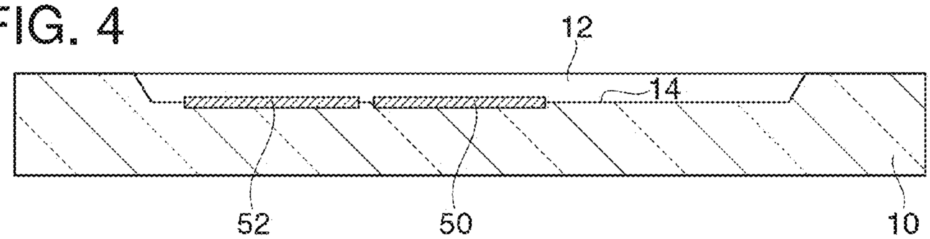
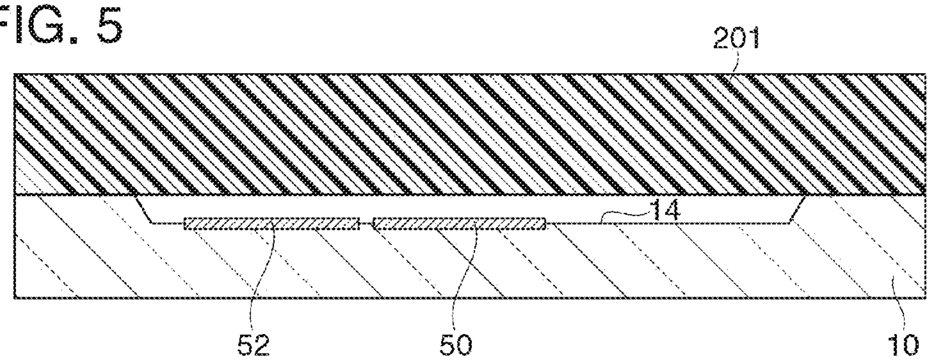


FIG. 5



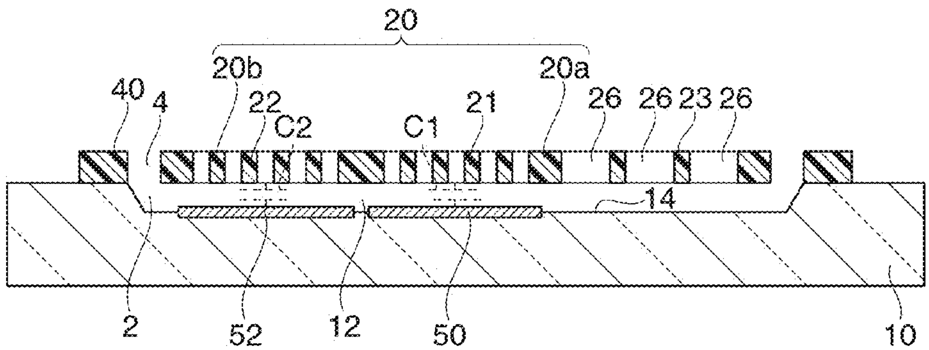
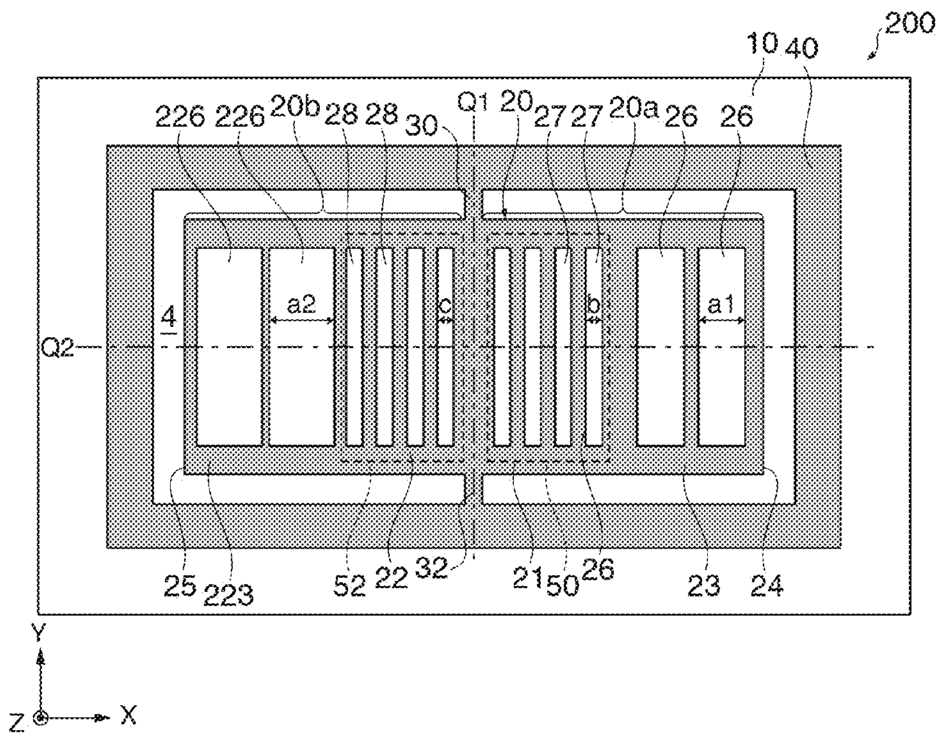

20
20b
20a
40
4
22
C2
C1
21
26
26
23
26
14
2
52
12
50
10

FIG. 6


200
10
40
226
226
20b
28
28
30
Q1
20
27
27
20a
26
26
a2
c
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25
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22
32
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50
26
23
24
Y
Z
X

FIG. 7

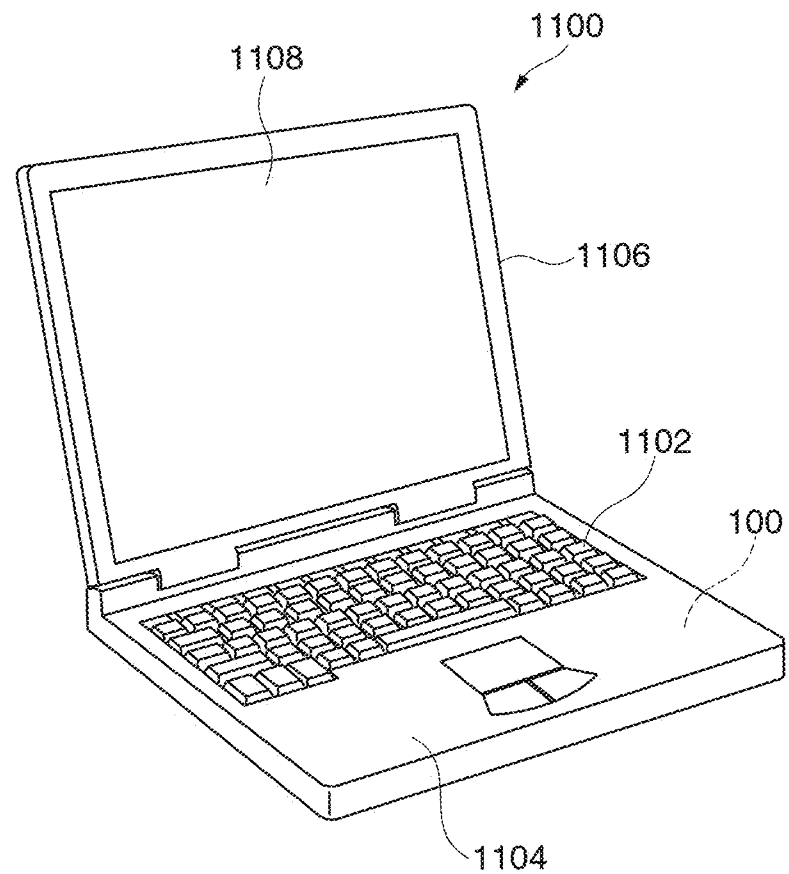

FIG. 8

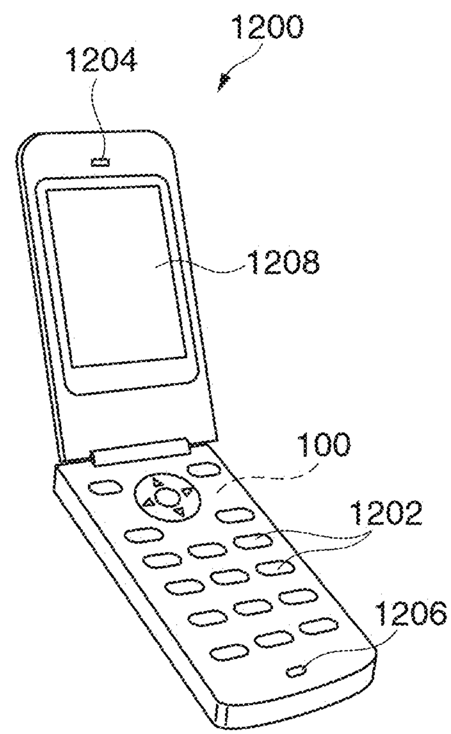

FIG. 9

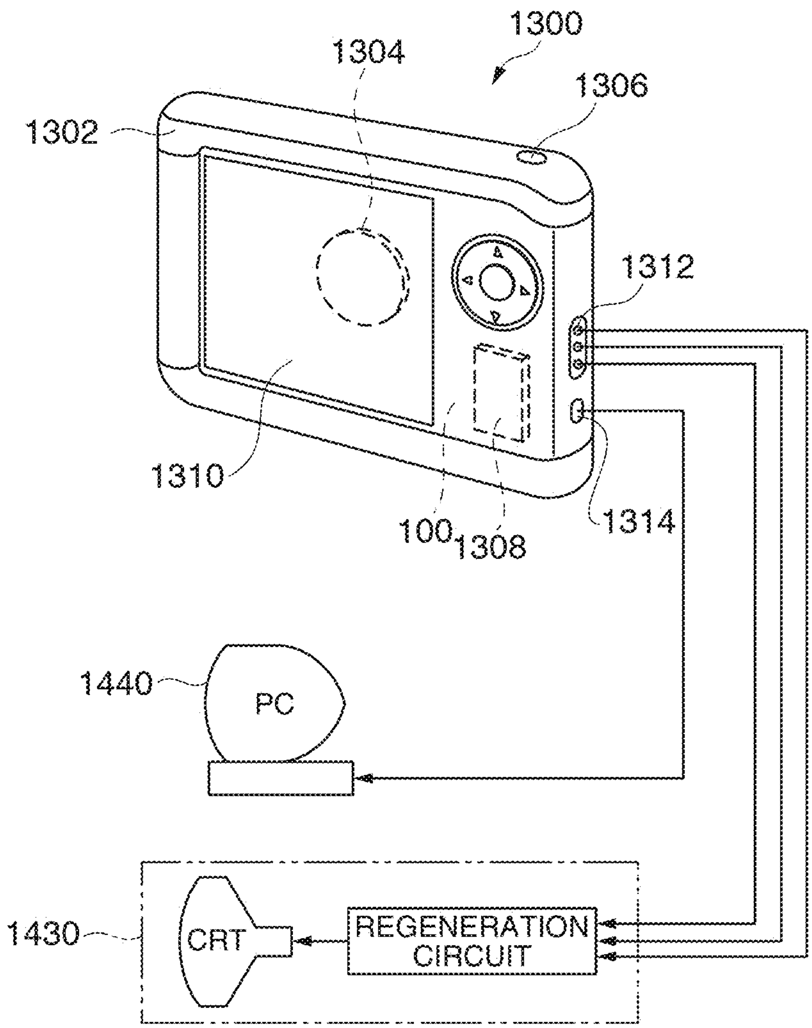
1300
1304
1306
1302
1312
1310
100
1308
1314
1440
PC
1430
CRT
REGENERATION
CIRCUIT

FIG. 10

PHYSICAL QUANTITY SENSOR AND ELECTRONIC APPARATUS

BACKGROUND

1. Technical Field

The present invention relates to a physical quantity sensor and an electronic apparatus.

2. Related Art

In recent years, techniques for realizing a physical quantity sensor that is small and has high sensitivity have been developed using, for example, a silicon MEMS (Micro Electro Mechanical Systems) technique.

For example, JP-T-2009-537803 (Patent Document 1) discloses an acceleration sensor with a mass having two wings rotatable about a torsion web. The acceleration sensor is configured such that through-holes are disposed in each of the two wings and thus torsions of the same magnitude in opposite directions relative to the torsion web cause damping torques of the same magnitude. Moreover, the acceleration sensor has a first electrode below one of the wings and a second electrode below the other wing. The acceleration sensor detects acceleration based on an electrostatic capacitance between the one wing and the first electrode and an electrostatic capacitance between the other wing and the second electrode.

In the acceleration sensor of Patent Document 1, the mass is accommodated in a casing filled with a gas such as nitrogen. By disposing the through-holes in the wing, damping (action to stop the movement of the mass, or flow resistance) caused by the viscosity of the gas can be reduced. With this configuration, the detection sensitivity can be enhanced.

However, in the acceleration sensor of Patent Document 1, since the size of the through-hole is different between the two wings, the area of a region where the one wing overlaps with the first electrode in plan view is different from the area of a region where the other wing overlaps with the second electrode in plan view. Therefore, in an initial state (state where acceleration is not applied, or state where the wings are horizontal), the electrostatic capacitance between the one wing and the first electrode is different from the electrostatic capacitance between the other wing and the second electrode. Hence, for eliminating the difference between the initial capacitances, an adjustment of a gap between the wing and the electrode, or a circuit or the like for correcting the difference between the initial capacitances is required. Therefore, the configuration of an apparatus cannot be simplified, leading to problems such as increases in manufacturing processes and cost.

SUMMARY

An advantage of some aspects of the invention is to provide a physical quantity sensor that has a simple configuration and can enhance detection sensitivity. Another advantage of some aspects of the invention is to provide an electronic apparatus having the physical quantity sensor.

The invention can be implemented as the following modes or application examples.

Application Example 1

A physical quantity sensor according to this application example includes: a movable body displaceable about a first axis as an axis of rotation and including, with the first axis as a boundary in plan view, a first movable electrode portion

disposed in a first region, a second movable electrode portion disposed in a second region, and a damping adjusting portion disposed in at least one of the first region and the second region; a beam portion supporting the movable body; a first fixed electrode portion arranged to face the first movable electrode portion; and a second fixed electrode portion arranged to face the second movable electrode portion, wherein a first through-hole is disposed in the damping adjusting portion, a second through-hole is disposed in the first movable electrode portion and the second movable electrode portion, in a portion excepting the second through-holes in plan view, the area of a region where the first movable electrode portion overlaps with the first fixed electrode portion is the same as the area of a region where the second movable electrode portion overlaps with the second fixed electrode portion, and the width of the first through-hole is greater than the width of the second through-hole.

According to the physical quantity sensor, in the portion excepting the second through-holes in plan view, the area of the region where the first movable electrode portion overlaps with the first fixed electrode portion is the same as the area of the region where the second movable electrode portion overlaps with the second fixed electrode portion. Therefore, in an initial state (for example, a state where the movable body is horizontal), an electrostatic capacitance between the first movable electrode portion and the first fixed electrode portion can be made equal to an electrostatic capacitance between the second movable electrode portion and the second fixed electrode portion with a simple configuration. Further, the width of the through-hole disposed in the damping adjusting portion is greater than the width of the through-hole disposed in the first movable electrode portion and the second movable electrode portion. Therefore, damping (action to stop the movement of the movable body, or flow resistance) can be efficiently reduced while securing the area of the first movable electrode portion and the area of the second movable electrode portion. Hence, according to the physical quantity sensor, a simple configuration is provided, and the detection sensitivity can be enhanced.

Application Example 2

In the physical quantity sensor according to the application example, the mass of the first region of the movable body and the mass of the second region of the movable body may be different from each other.

According to the physical quantity sensor of this configuration, when acceleration in the vertical direction is applied for example, a rotation moment of the first region of the movable body and a rotation moment of the second region of the movable body are not balanced, so that a predetermined inclination can be produced in the movable body.

Application Example 3

In the physical quantity sensor according to the application example, the total area of an opening surface of the second through-hole disposed in the first movable electrode portion, the opening surface being on the first fixed electrode portion side, may be the same as the total area of an opening surface of the second through-hole disposed in the second movable electrode portion, the opening surface being on the second fixed electrode portion side.

According to the physical quantity sensor of this configuration, a simple configuration is provided, and since an initial capacitance between the first movable electrode portion and the first fixed electrode portion can be made equal to an initial capacitance between the second movable electrode portion and the second fixed electrode portion, the accuracy of detection sensitivity can be further enhanced.

Application Example 4

In the physical quantity sensor according to the application example, the second through-hole may extend in a direction of the first axis.

According to the physical quantity sensor of this configuration, damping can be efficiently reduced while securing the area of the first movable electrode portion and the area of the second movable electrode portion.

Application Example 5

In the physical quantity sensor according to the application example, a plurality of at least one of the first through-holes and the second through-holes may be disposed.

According to the physical quantity sensor of this configuration, damping can be more reduced.

Application Example 6

In the physical quantity sensor according to the application example, the damping adjusting portion may be disposed at an edge portion of the movable body in a direction of a second axis crossing the first axis.

According to the physical quantity sensor of this configuration, since the first through-hole can be disposed at a point away from the first axis serving as the axis of rotation, damping can be efficiently reduced.

Application Example 7

In the physical quantity sensor according to the application example, the damping adjusting portion may be disposed in both of the first region and the second region, and the width of the first through-hole of the damping adjusting portion disposed in the first region may be greater than the width of the first through-hole of the damping adjusting portion disposed in the second region.

According to the physical quantity sensor of this configuration, a simple configuration is provided, and the detection sensitivity can be enhanced.

Application Example 8

An electronic apparatus according to this application example includes the physical quantity sensor according to the application example.

According to the electronic apparatus, since the physical quantity sensor according to the application example is included, a simple configuration is provided, and the detection sensitivity can be enhanced.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described with reference to the accompanying drawings, wherein like numbers reference like elements.

FIG. **1** is a plan view schematically showing a physical quantity sensor according to an embodiment.

FIG. **2** is a cross-sectional view schematically showing the physical quantity sensor according to the embodiment.

FIG. **3** explains a relation between through-holes and damping.

FIG. **4** is a cross-sectional view schematically showing a manufacturing process of the physical quantity sensor according to the embodiment.

FIG. **5** is a cross-sectional view schematically showing a manufacturing process of the physical quantity sensor according to the embodiment.

FIG. **6** is a cross-sectional view schematically showing a manufacturing process of the physical quantity sensor according to the embodiment.

FIG. **7** is a plan view schematically showing a modified example of a physical quantity sensor according to the embodiment.

FIG. **8** is a perspective view schematically showing an electronic apparatus according to the embodiment.

FIG. **9** is a perspective view schematically showing an electronic apparatus according to the embodiment.

FIG. **10** is a perspective view schematically showing an electronic apparatus according to the embodiment.

DESCRIPTION OF EXEMPLARY EMBODIMENTS

Hereinafter, a preferred embodiment of the invention will be described in detail using the drawings. The embodiment described below does not unduly limit the contents of the invention set forth in the appended claims. Moreover, not all of configurations described below are indispensable constituent features of the invention.

1. Physical Quantity Sensor

First, a physical quantity sensor according to an embodiment will be described with reference to the drawings. FIG. **1** is a plan view schematically showing the physical quantity sensor **100** according to the embodiment. FIG. **2** is a cross-sectional view schematically showing the physical quantity sensor **100** according to the embodiment. FIG. **2** is the cross-sectional view taken along line II-II of FIG. **1**. Moreover, for convenience sake, the illustration of a lid **60** is omitted in FIG. **1**. In FIGS. **1** and **2**, the X-axis, the Y-axis, and the Z-axis are illustrated as three axes perpendicular to each other.

The physical quantity sensor **100** can be used as, for example, an inertial sensor. Specifically, the physical quantity sensor **100** can be used as, for example, an acceleration sensor (electrostatic capacitive acceleration sensor or electrostatic capacitive MEMS acceleration sensor) for measuring acceleration in the vertical direction (Z-axis direction).

As shown in FIGS. **1** and **2**, the physical quantity sensor **100** includes a support substrate (substrate) **10**, a movable body **20**, beam portions **30** and **32**, a first fixed electrode portion **50**, and a second fixed electrode portion **52**. The physical quantity sensor **100** can further include a fixed portion **40** and the lid **60**.

The first fixed electrode portion **50** and the second fixed electrode portion **52** are disposed on the support substrate **10**. In the illustrated example, the fixed electrode portions **50** and **52** are disposed on a surface **14** of the support substrate **10**, where the surface **14** defines a bottom surface of a recess **12**. The surface **14** of the support substrate **10** on which the fixed electrode portions **50** and **52** are disposed is a flat surface. The surface **14** of the support substrate **10** is parallel to the movable body **20** when the movable body **20** is horizontal (parallel to the XY-plane). The fixed portion **40** and the lid **60** are bonded to the support substrate **10**. The support substrate **10** and the lid **60** can form a space for accommodating the movable body **20**. In the space, an inert gas such as nitrogen, helium, or argon, for example, is filled. The material of the support substrate **10** is not particularly limited, but is, for example, an insulating material such as glass. For example, the support substrate **10** is formed of an insulating material such as glass and the movable body **20** is formed of a semiconductor material such as silicon, so that the movable body **20** and the support substrate **10** can be easily insulated from each other by bonding them together, and thus the sensor structure can be simplified.

The movable body **20** is disposed above the support substrate **10** with a gap **2**. The movable body **20** is supported by the first beam portion **30** and the second beam portion **32**. The movable body **20** is displaceable about a first axis Q**1** as an axis of rotation. Specifically, when acceleration in the vertical direction (Z-axis direction) is applied for example, the movable body **20** can rock in a seesaw manner about the first axis Q**1**, which is determined by the beam portions **30** and **32**, as the axis of rotation (rocking axis). The shape of the outer circumferential edge of the movable body **20** is, for example, a rectangle in plan view (as viewed from the Z-axis direction). Moreover, the thickness (size in the Z-axis direction) of the movable body **20** is, for example, constant.

The movable body **20** has a first seesaw piece **20***a* and a second seesaw piece **20***b*. The first seesaw piece **20***a* is a first region (portion located on the right of FIG. **1**) that is one of two regions of the movable body **20**, where the two regions are defined by the first axis Q**1** in plan view. The second seesaw piece **20***b* is a second region (portion located on the left of FIG. **1**) that is the other of the two regions of the movable body **20**, where the two regions are defined by the first axis Q**1** in plan view.

For example, when acceleration (for example, gravitational acceleration) in the vertical direction is applied to the movable body **20**, a rotation moment (moment of force) is generated in each of the first seesaw piece **20***a* and the second seesaw piece **20***b*. Here, when the rotation moment (for example, a clockwise rotation moment) of the first seesaw piece **20***a* and the rotation moment (for example, a counterclockwise rotation moment) of the second seesaw piece **20***b* are balanced, the inclination of the movable body **20** is not changed and thus a change in acceleration cannot be detected. Hence, the movable body **20** is designed such that when acceleration in the vertical direction is applied, the rotation moment of the first seesaw piece **20***a* and the rotation moment of the second seesaw piece **20***b* are not balanced and thus a predetermined inclination is produced in the movable body **20**.

In the physical quantity sensor **100**, the first axis Q**1** is arranged at a position shifted from the center (center of gravity) of the movable body **20** (distances from the first axis Q**1** to respective tips of the seesaw pieces **20***a* and **20***b* are differentiated from each other), so that the seesaw pieces **20***a* and **20***b* have masses different from each other. That is, the mass of the movable body **20** is different between one side thereof (the first seesaw piece **20***a*) and the other side thereof (the second seesaw piece **20***b*) with the first axis Q**1** as the boundary. In the illustrated example, a distance from the first axis Q**1** to an edge surface **24** of the first seesaw piece **20***a* is greater than a distance from the first axis Q**1** to an edge surface **25** of the second seesaw piece **20***b*. Moreover, the thickness of the first seesaw piece **20***a* is equal to the thickness of the second seesaw piece **20***b*. Hence, the mass of the first seesaw piece **20***a* is greater than the mass of the second seesaw piece **20***b*. Since the seesaw pieces **20***a* and **20***b* have masses different from each other as described above, when acceleration in the vertical direction is applied, the rotation moment of the first seesaw piece **20***a* and the rotation moment of the second seesaw piece **20***b* can be prevented from being balanced. Hence, when acceleration in the vertical direction is applied, a predetermined inclination can be produced in the movable body **20**.

Although not illustrated, the seesaw pieces **20***a* and **20***b* may have masses different from each other by arranging the first axis Q**1** at the center of the movable body **20** and differentiating the thicknesses of the seesaw pieces **20***a* and **20***b* from each other. Also in this case, when acceleration in the vertical direction is applied, a predetermined inclination can be produced in the movable body **20**.

The movable body **20** is disposed spaced apart from the support substrate **10**. In the illustrated example, the gap **2** is disposed between the movable body **20** and the support substrate **10**. Moreover, the movable body **20** is connected to the fixed portion **40** via the beam portions **30** and **32** while being spaced apart from the fixed portion **40**. A gap **4** is disposed between the movable body **20** and the fixed portion **40**. The gaps **2** and **4** are present around the movable body **20**, so that the movable body **20** can rock in a seesaw manner.

The movable body **20** has, in the first seesaw piece **20***a* on one side of the first axis Q**1** in plan view, a first movable electrode portion **21** and a damping adjusting portion **23**. Further, the movable body **20** has, in the second seesaw piece **20***b* on the other side of the first axis Q**1** in plan view, a second movable electrode portion **22**.

The first movable electrode portion **21** is a portion of the movable body **20**, where the portion overlaps with the first fixed electrode portion **50** in plan view. The first movable electrode portion **21** is a portion of the movable body **20**, where the portion forms an electrostatic capacitance C**1** with the first fixed electrode portion **50**. In the first movable electrode portion **21**, through-holes (second through-holes) **27** penetrating through the movable body **20** in its thickness direction (Z-axis direction) are disposed. In the illustrated example, the plurality of (five) through-holes **27** are disposed in the first movable electrode portion **21**.

The second movable electrode portion **22** is a portion of the movable body **20**, where the portion overlaps with the second fixed electrode portion **52** in plan view. The second movable electrode portion **22** is a portion of the movable body **20**, where the portion forms an electrostatic capacitance C**2** with the second fixed electrode portion **52**. In the second movable electrode portion **22**, through-holes (second through-holes) **28** penetrating through the movable body **20** in its thickness direction are disposed. In the second movable electrode portion **22**, the plurality of (five) through-holes **28** are disposed. In the physical quantity sensor **100**, the movable body **20** may be composed of an electrically-conductive material to thereby form the movable electrode portions **21** and **22**. Moreover, a movable electrode portion formed of a conductor layer such as of a metal can be formed on the surface of the movable body **20**. In the illustrated example, the movable body **20** is composed of an electrically-conductive material (silicon doped with an impurity) to thereby form the movable electrode portions **21** and **22**.

The damping adjusting portion **23** is a portion of the movable body **20**, where the portion does not overlap with the fixed electrode portions **50** and **52** in plan view. In the illustrated example, the damping adjusting portion **23** is disposed at an edge portion of the movable body **20** in a direction of a second axis Q**2** (direction along the second axis Q**2**). Here, the second axis Q**2** is an axis perpendicular to the first axis Q**1**. In the first seesaw piece **20***a*, the first movable electrode portion **21** and the damping adjusting portion **23** are arranged side by side in this order from the first axis Q1 side in the direction of the second axis Q2 (positive X-axis direction in the illustrated example). In the damping adjusting portion **23**, through-holes (first through-holes) **26** penetrating through the movable body **20** in its thickness direction are disposed. In the illustrated example, the plurality of (three) through-holes **26** are disposed in the damping adjusting portion **23**. The numbers of the through-holes **26**, **27**, and **28** are not particularly limited. By adjusting the number or area of the through-holes **26** in the damping adjusting portion **23**, the damping of the movable body **20** can be adjusted.

The through-holes **26**, **27**, and **28** serve as gas flow paths in rocking (rotation) of the movable body **20**. Therefore, damping (action to stop the movement of the movable body, or flow resistance) caused by the viscosity of gas in rocking of the movable body **20** can be reduced by the through-holes **26**, **27**, and **28**. Hence, the detection sensitivity can be enhanced. Moreover, since the respective pluralities of through-holes **26**, through-holes **27**, and through-holes **28** are disposed, damping can be more reduced and thus the detection sensitivity can be more enhanced.

A width a of the through-hole **26** is greater than a width b of the through-hole **27** and a width c of the through-hole **28**. Here, the width of the through-hole is the size of the through-hole in the direction of the second axis Q2 perpendicular to the first axis Q1 serving as the axis of rotation, and in the illustrated example, is the size of the through-hole in the X-axis direction. By making the width a of the through-hole **26** greater than the width b of the through-hole **27** and the width c of the through-hole **28**, damping can be efficiently reduced while securing the areas of the movable electrode portions **21** and **22**. The reason will be described below.

FIG. **3** explains a relationship between through-holes and damping. In FIG. **3**, a model M1 and a model M2 each having movable electrode portions **1021** and a fixed electrode portion **1050** are illustrated. Specifically, a width w**1** of the movable electrode portion **1021** of the model M1 is twice a width w**2** of the movable electrode portion **1021** of the model M**2**. Moreover, an interval **51** between the movable electrode portions **1021** next to each other in the model M1 is twice an interval S2 between the movable electrode portions **1021** next to each other in the model M2. Moreover, a length L**1** of the movable electrode portion **1021** of the model M1 is the same as a length L**2** of the movable electrode portion **1021** of the model M**2**. Therefore, the total area (2×w**1**×L**1**) of the movable electrode portions **1021** of the model M1 is equal to the total area (4×w**2**×L**2**) of the movable electrode portions **1021** of the model M**2**. The total area (2×S**1**×L**1**) of the intervals between the movable electrode portions **1021** of the model M1 is equal to the total area (4×S**2**×L**2**) of the intervals between the movable electrode portions **1021** of the model M**2**.

Here, due to the movement of the movable electrode portion **1021**, gas between the electrode portions **1021** and **1050** moves. At that time, in regard to the movement of the movable electrode portion **1021**, action to stop the movement of the movable electrode portion, that is, damping is caused by the viscosity of the gas. When the width of the movable electrode portion **1021** is w, the length of the movable electrode portion **1021** is L, a distance between the movable electrode portion **1021** and the fixed electrode portion **1050** is d, and the number of pairs of the electrode portions **1021** and **1050** is n, a damping coefficient D representing the magnitude of damping can be expressed by the following equation (1).

$$D = n\eta L\left(\frac{w}{d}\right)^3 \quad (1)$$

where η is the viscosity coefficient of the air

Based on the equation (1), the damping coefficient D of the model M**2** is ¼ of the damping coefficient D of the model M**1**. This is because the damping coefficient D is proportional to the cube of the width w of the movable electrode portion **1021**. In the model M**2** as described above, the damping coefficient D can be reduced (damping can be reduced) compared to the model M**1**, in spite of the fact that the area of the movable electrode portion **1021** is the same as that of the model M**1**. It is found from the result that by reducing an interval between movable electrode portions next to each other and reducing the width of the movable electrode portion, damping can be efficiently reduced while securing the area of the movable electrode portion.

Hence, in the physical quantity sensor **100**, damping can be efficiently reduced by reducing the widths b and c of the through-holes **27** and **28**, and securing (or maintaining) the areas of the movable electrode portions **21** and **22**. Further, since there is no need to secure (and also enlarge) the area in the damping adjusting portion **23**, damping can be reduced more by forming a wider through-hole **26**, compared to the through-holes **27** and **28** disposed in the movable electrode portions **21** and **22**.

The through-hole **26** disposed in the damping adjusting portion **23** extends in the direction of the first axis Q1 as shown in FIG. **1**. The planar shape of the through-hole **26** is, for example, a rectangle having long sides parallel to the first axis Q1 and short sides parallel to the second axis Q**2**. The plurality of (three) through-holes **26** disposed in the damping adjusting portion **23** are aligned along the second axis Q2 (in the X-axis direction). The plurality of through-holes **26** have the same width a and length (size in the Y-axis direction). That is, the plurality of through-holes **26** have the same shape. The plurality of through-holes **26** may each have a different shape.

The through-hole **27** disposed in the first movable electrode portion **21** extends in the direction of the first axis Q**1**. In the illustrated example, the planar shape of the through-hole **27** is a rectangle having long sides parallel to the first axis Q1 and short sides parallel to the second axis Q**2**. Therefore, in the first movable electrode portion **21**, the planar shape of a portion between the through-holes **27** next to each other can be made into a rectangle having long sides parallel to the first axis Q1 and short sides parallel to the second axis Q**2**. Hence, damping can be efficiently reduced while securing the area of the first movable electrode portion **21**. The plurality of (five) through-holes **27** disposed in the first movable electrode portion **21** are aligned along the second axis Q**2**. The plurality of through-holes **27** have the same width b and length. That is, the plurality of through-holes **27** have the same shape. The plurality of through-holes **27** may each have a different shape.

The through-hole **28** disposed in the second movable electrode portion **22** extends in the direction of the first axis Q**1**. In the illustrated example, the planar shape of the through-hole **28** is a rectangle having long sides parallel to the first axis Q1 and short sides parallel to the second axis Q**2**. Therefore, in the second movable electrode portion **22**, the planar shape of a portion between the through-holes **28** next to each other can be made into a rectangle having long sides parallel to the first axis Q1 and short sides parallel to the second axis Q**2**. Hence, damping can be efficiently reduced while securing the area of the second movable electrode portion **22**. The plurality of (five) through-holes **28** disposed in the second movable electrode portion **22** are aligned along the second axis Q**2**. The plurality of through-holes **28** have the same width c and length. That is, the plurality of through-holes **28** have the same shape. The plurality of through-holes **28** may each have a different shape.

In the illustrated example, the fixed electrode portions **50** and **52** are located inside the outer circumferential edge of the movable body **20** in plan view. Therefore, the area of a region where the first movable electrode portion **21** overlaps with the first fixed electrode portion **50** is equal to that obtained by subtracting, from the area of the first fixed electrode portion **50**, the total area of the through-holes disposed in the first movable electrode portion **21**. Moreover, the area of a region where the second movable electrode portion **22** overlaps with the second fixed electrode portion **52** is equal to that obtained by subtracting, from the area of the second fixed electrode portion **52**, the total area of the through-holes **28** disposed in the second movable electrode portion **22**.

Here, the through-hole **27** and the through-hole **28** have the same shape, and the area of the through-hole **27** (area of an opening) is equal to the area of the through-hole **28** (area of an opening). Moreover, the number of the through-holes **27** is equal to the number of the through-holes **28**. That is, the total area of the through-holes **27** disposed in the first movable electrode portion **21** is equal to the total area of the through-holes **28** disposed in the second movable electrode portion **22**. Moreover, the area of the first fixed electrode portion **50** is equal to the area of the second fixed electrode portion **52**. Hence, in a portion excepting the second through-holes **27** and **28** in plan view, the area of the region where the first movable electrode portion **21** overlaps with the first fixed electrode portion **50** is equal to the area of the region where the second movable electrode portion **22** overlaps with the second fixed electrode portion **52**. Therefore, in an initial state (state where the movable body is horizontal), the electrostatic capacitance C**1** between the first movable electrode portion **21** and the first fixed electrode portion **50** can be made equal to the electrostatic capacitance C**2** between the second movable electrode portion **22** and the second fixed electrode portion **52**.

The first fixed electrode portion **50** is disposed at a position of the support substrate **10** at which the support substrate **10** faces the first movable electrode portion **21**. The electrostatic capacitance C**1** is formed by the first movable electrode portion **21** and the first fixed electrode portion **50**. Moreover, the second fixed electrode portion **52** is disposed at a position of the support substrate **10** at which the support substrate **10** faces the second movable electrode portion **22**. The electrostatic capacitance C**2** is formed by the second movable electrode portion **22** and the second fixed electrode portion **52**. The electrostatic capacitance C**1** and the electrostatic capacitance C**2** are configured such that, for example, in the initial state (state where the movable body **20** is horizontal), they are equal to each other. The positions of the first movable electrode portion **21** and the second movable electrode portion **22** change according to the movement of the movable body **20**. According to changes in the position of the movable electrode portions **21** and **22**, the electrostatic capacitances C**1** and C**2** are changed. A predetermined potential is given to the movable body **20** via, for example, the beam portions **30** and **32**.

Although not illustrated, the first fixed electrode portion **50** may be disposed at a position of the lid **60** at which the lid **60** faces the first movable electrode portion **21**, and the second fixed electrode portion **52** may be disposed at a position of the lid **60** at which the lid **60** faces the second movable electrode portion **22**.

The first beam portion **30** and the second beam portion **32** support the movable body **20** displaceably about the first axis Q**1**. The beam portions **30** and **32** function as torsion springs. With this configuration, the beam portions **30** and **32** have a high resilience against torsion deformation caused in the beam portions **30** and **32** due to the movable body **20** rocking in a seesaw manner, so that the breakage of the beam portions **30** and **32** can be prevented.

The first beam portion **30** and the second beam portion **32** are arranged on the first axis Q**1** in plan view as shown in FIG. **1**. The beam portions **30** and **32** extend on the first axis Q**1** from the fixed portion **40** to the movable body **20**. The beam portions **30** and **32** are members to determine the position of the first axis Q**1** serving as the axis of rotation (rocking axis) of the movable body **20**. The beam portions **30** and **32** connect the fixed portion **40** with the movable body **20**. The first beam portion **30** is connected to a side surface of the movable body **20** on the positive Y-axis direction side, while the second beam portion **32** is connected to a side surface of the movable body **20** on the negative Y-axis direction side.

The fixed portion **40** is disposed around the movable body **20** in plan view. In the illustrated example, the fixed portion **40** is disposed so as to surround the movable body **20** in plan view. The shape of the fixed portion **40** is not particularly limited. The fixed portion **40** is fixed to the support substrate **10**. The fixed portion **40** and the movable body **20** are spaced apart from each other. The gap **4** is disposed between the fixed portion **40** and the movable body **20**.

The movable body **20**, the beam portions **30** and **32**, and the fixed portion **40** are integrally disposed. The movable body **20**, the beam portions **30** and **32**, and the fixed portion **40** are integrally disposed by patterning one substrate (for example, a silicon substrate).

The first fixed electrode portion **50** is disposed on the support substrate **10**. The first fixed electrode portion **50** is arranged at a position facing the first movable electrode portion **21**. Above the first fixed electrode portion **50**, the first movable electrode portion **21** is located with the gap **2**. The first fixed electrode portion **50** is disposed so as to form the electrostatic capacitance C**1** with the first movable electrode portion **21**.

The second fixed electrode portion **52** is disposed on the support substrate **10**. The second fixed electrode portion **52** is arranged at a position facing the second movable electrode portion **22**. Above the second fixed electrode portion **52**, the second movable electrode portion **22** is located with the gap. The second fixed electrode portion **52** is disposed so as to form the electrostatic capacitance C**2** with the second movable electrode portion **22**. The area of the first fixed electrode portion **50** is equal to the area of the second fixed electrode portion **52**. The planar shape of the first fixed electrode portion **50** and the planar shape of the second fixed electrode portion **52** are symmetrical to each other with respect to, for example, the first axis Q**1**.

The material of the fixed electrode portions **50** and **52** is, for example, aluminum, gold, ITO (Indium Tin Oxide), or the like. The material of the fixed electrode portions **50** and **52** desirably a transparent electrode material such as ITO. This is because, with the use of a transparent electrode material as the fixed electrode portions **50** and **52**, when the support substrate **10** is a transparent substrate (glass substrate), a foreign substance or the like existing on the fixed electrode portions **50** and **52** can be visually recognized easily.

The lid **60** is placed on the support substrate **10**. As the lid **60**, a silicon substrate (substrate made of silicon), for example, can be used. When a glass substrate is used as the support substrate **10**, the support substrate **10** and the lid **60** may be bonded together by anodic bonding.

Next, the operations of the physical quantity sensor **100** will be described. In the physical quantity sensor **100**, the movable body **20** rocks (rotates) about the first axis Q**1** according to a physical quantity such as acceleration or angular velocity. With the movement of the movable body **20**, a distance between the first movable electrode portion **21** and the first fixed electrode portion **50** and a distance between the second movable electrode portion **22** and the second fixed electrode portion **52** are changed. Specifically, one of the distance between the electrode portions **21** and **50** and the distance between the electrode portions **22** and **52** is increased, while the other distance is reduced. Therefore, due to the rocking (rotation) of the movable body **20**, one of the electrostatic capacitances C**1** and C**2** is increased, while the other is reduced. Hence, based on the difference between the electrostatic capacitance C**1** and the electrostatic capacitance C**2** (by a so-called differential capacitance detection method), a physical quantity such as acceleration or angular velocity can be detected.

As described above, the physical quantity sensor **100** can be used as an inertial sensor such as an acceleration sensor or a gyro sensor. Specifically, the physical quantity sensor **100** can be used as, for example, an electrostatic capacitive acceleration sensor for measuring acceleration in the vertical direction.

The physical quantity sensor **100** according to the embodiment has, for example, the following features.

In the physical quantity sensor **100**, the movable body **20** has, with the first axis Q**1** serving as the axis of rotation as the boundary, the first movable electrode portion **21** and the damping adjusting portion **23** disposed in the first seesaw piece **20***a* and the second movable electrode portion **22** disposed in the second seesaw piece **20***b*. In the portion excepting the second through-holes **27** and **28** in plan view, the area of the region where the first movable electrode portion **21** overlaps with the first fixed electrode portion **50** is equal to the area of the region where the second movable electrode portion **22** overlaps with the second fixed electrode portion **52**. With this configuration, in the initial state (state where the movable body is horizontal), the electrostatic capacitance C**1** between the first movable electrode portion **21** and the first fixed electrode portion **50** can be made equal to the electrostatic capacitance C**2** between the second movable electrode portion **22** and the second fixed electrode portion **52**. Hence, for example, for eliminating a difference between an initial capacitance between the electrode portions **21** and **50** and an initial capacitance between the electrode portions **22** and **52**, an adjustment of the gap between the movable electrode portion and the fixed electrode portion, or a circuit or the like for correcting the difference between the initial capacitances is not required, so that an apparatus can be made to have a simple configuration. According to the physical quantity sensor **100** as described above, the electrostatic capacitances C**1** and C**2** in the initial state can be made equal to each other with a simple configuration.

Further, in the physical quantity sensor **100**, the width a of the through-hole **26** disposed in the damping adjusting portion **23** is greater than the widths b and c of the through-holes **27** and **28** disposed in the movable electrode portions **21** and **22**. With this configuration, damping can be efficiently reduced while securing the areas of the movable electrode portions **21** and **22**. Moreover, there is no need to secure (increase) the area in the damping adjusting portion **23**, damping can be more reduced by forming the through-hole **26** with a greater width compared to the through-holes **27** and **28** disposed in the movable electrode portions **21** and **22**. Hence, according to the physical quantity sensor **100**, the detection sensitivity can be enhanced. According to the physical quantity sensor **100** as described above, a simple configuration is provided, and the detection sensitivity can be enhanced.

In the physical quantity sensor **100**, the mass of the first seesaw piece **20***a* of the movable body **20** is different from the mass of the second seesaw piece **20***b* of the movable body **20**. Therefore, when acceleration in the vertical direction is applied for example, the rotation moment of one side (the first seesaw piece **20***a*) of the movable body **20** and the rotation moment of the other side (the second seesaw piece **20***b*) of the movable body **20** are not balanced, so that a predetermined inclination can be produced in the movable body.

In the physical quantity sensor **100**, the area of the through-hole **27** disposed in the first movable electrode portion **21** is equal to the area of the through-hole **28** disposed in the second movable electrode portion **22**. With this configuration, the electrostatic capacitances C**1** and C**2** in the initial state can be made equal to each other with a simple configuration.

Moreover, in the physical quantity sensor **100**, the total area of the through-holes **27** disposed in the first movable electrode portion **21** is equal to the total area of the through-holes **28** disposed in the second movable electrode portion **22**. With this configuration, the electrostatic capacitances C**1** and C**2** in the initial state can be made equal to each other with a simple configuration.

In the physical quantity sensor **100**, the through-holes **27** and **28** disposed in the movable electrode portions **21** and **22** extend in the direction of the first axis Q**1** in plan view. With this configuration, damping can be efficiently reduced while securing the areas of the movable electrode portions **21** and **22**.

In the physical quantity sensor **100**, the plurality of through-holes **26** are disposed in the damping adjusting portion **23**. Moreover, the plurality of through-holes **27** are disposed in the first movable electrode portion **21**, and the plurality of through-holes **28** are disposed in the second movable electrode portion **22**. With this configuration, damping can be more reduced.

In the physical quantity sensor **100**, the damping adjusting portion **23** is disposed at the edge portion of the movable body **20** in the direction of the second axis Q**2**. With this configuration, since the through-holes **26** can be disposed at points away from the first axis Q**1** serving as the axis of rotation, damping can be efficiently reduced.

2. Method for Manufacturing Physical Quantity Sensor

Next, a method for manufacturing the physical quantity sensor according to the embodiment will be described with reference to the drawings. FIGS. **4** to **6** are cross-sectional views schematically showing manufacturing processes of the physical quantity sensor **100** according to the embodiment.

As shown in FIG. **4**, a glass substrate is etched and the recess **12** is formed in the glass substrate for example, whereby the support substrate **10** is obtained. The etching is performed by, for example, wet etching.

Next, the first fixed electrode portion **50** and the second fixed electrode portion **52** are formed on the surface **14** of the support substrate **10**, where the surface **14** defines the bottom surface of the recess **12**. The fixed electrode portions **50** and **52** are formed by depositing a conductive layer on the surface **14** of the support substrate **10** by a sputtering method or the like and then patterning the conductive layer using a photolithographic technique and an etching technique.

As shown in FIG. **5**, a silicon substrate **201** (sensor substrate) is bonded to the support substrate **10**. The bonding of the support substrate **10** with the silicon substrate **201** is performed by, for example, anodic bonding or direct bonding, or using adhesive.

As shown in FIG. **6**, after thinning the silicon substrate **201** by, for example, grinding using a grinding machine, the silicon substrate **201** is patterned into a desired shape to form the movable body **20**, the beam portions **30** and **32**, and the fixed portion **40**. Further, the through-holes **26**, **27**, and **28** are formed in the movable body **20**. The patterning is performed by a photolithographic technique and an etching technique (dry etching), and as a more specific etching technique, the Bosch process can be used. In this process, the movable body **20**, the beam portions **30** and **32**, and the fixed portion **40** are integrally formed by patterning (etching) the silicon substrate **201**.

As shown in FIGS. **1** and **2**, the lid **60** is bonded to the support substrate **10** to accommodate the movable body **20** in a space formed by the support substrate **10** and the lid **60**. The bonding of the support substrate **10** with the lid **60** is performed by, for example, anodic bonding, or using adhesive or the like. This process is performed in an inert gas atmosphere, whereby an inert gas can be filled in the space in which the movable body **20** is accommodated.

Through the processes described above, the physical quantity sensor **100** can be manufactured.

3. Modified Example of Physical Quantity Sensor

Next, a physical quantity sensor according to a modified example of the embodiment will be described with reference to the drawing. FIG. **7** is a plan view schematically showing the physical quantity sensor **200** according to the modified example of the embodiment. Hereinafter, in the physical quantity sensor **200**, members having functions similar to those of the constituent members of the physical quantity sensor **100** described above are denoted by the same reference numerals and signs, and the detailed descriptions thereof are omitted.

In the physical quantity sensor **100** described above as shown in FIG. **1**, the first axis Q**1** serving as the axis of rotation is arranged at a position shifted from the center (center of gravity) of the movable body **20**.

In contrast to this, in the physical quantity sensor **200** as shown in FIG. **7**, the first axis Q**1** serving as the axis of rotation is arranged so as to pass through the center (center of gravity) of the movable body **20**.

The movable body **20** has the first movable electrode portion **21** and the damping adjusting portion **23** (first damping adjusting portion **23**) on one side (the first seesaw piece **20***a*) of the first axis Q**1** and the second movable electrode portion **22** and a second damping adjusting portion **223** on the other side (the second seesaw piece **20***b*) of the first axis Q**1**.

The second damping adjusting portion **223** is a portion of the second seesaw piece **20***b*, where the portion does not overlap with the second fixed electrode portion **52** in plan view. In the illustrated example, the second damping adjusting portion **223** is disposed at an edge portion of the movable body **20** in the direction of the second axis Q**2** (direction along the second axis Q**2**). In the second damping adjusting portion **223**, through-holes **226** penetrating through the movable body **20** in its thickness direction are disposed. In the illustrated example, the plurality of (two) through-holes **226** are disposed in the second damping adjusting portion **223**. By adjusting the numbers or areas of the through-holes **26** and **226** in the damping adjusting portions **23** and **223**, the damping of the movable body **20** can be adjusted.

A width a**2** of the through-hole **226** disposed in the second damping adjusting portion **223** is greater than a width a**1** of the through-hole **26** disposed in the first damping adjusting portion **23**. Therefore, the mass of the first seesaw piece **20***a* is greater than the mass of the second seesaw piece **20***b*. Hence, when acceleration in the vertical direction is applied for example, the rotation moment of one side (the first seesaw piece **20***a*) of the movable body **20** and the rotation moment of the other side (the second seesaw piece **20***b*) of the movable body **20** are not balanced, so that a predetermined inclination can be produced in the movable body.

According to the physical quantity sensor **200**, the widths a**1** and a**2** of the through-holes **26** and **226** disposed in the damping adjusting portions **23** and **223** are greater than the widths b and c of the through-holes **27** and **28** disposed in the movable electrode portions **21** and **22**. With this configuration, similarly to the physical quantity sensor **100**, damping can be efficiently reduced while securing the areas of the movable electrode portions **21** and **22**. Moreover, there is no need to increase the areas in the damping adjusting portions **23** and **223**. Therefore, damping can be more reduced by forming the through-holes **26** and **226** with a greater width compared to the through-holes **27** and **28** disposed in the movable electrode portions **21** and **22**. Hence, according to the physical quantity sensor **200**, the detection sensitivity can be enhanced. Further, since the area of the region where the first movable electrode portion **21** overlaps with the first fixed electrode portion **50** is equal to the area of the region where the second movable electrode portion **22** overlaps with the second fixed electrode portion **52**, the electrostatic capacitances C**1** and C**2** in the initial state can be made equal to each other with a simple configuration.

4. Electronic Apparatuses

Next, electronic apparatuses according to the embodiment will be described with reference to the drawings. The electronic apparatuses according to the embodiment include any of the physical quantity sensors according to the embodiment of the invention. In the following, electronic apparatuses including the physical quantity sensor **100** as the physical quantity sensor according to the embodiment of the invention will be described.

FIG. **8** is a perspective view schematically showing a mobile (or notebook) personal computer **1100** as an electronic apparatus according to the embodiment.

As shown in FIG. **8**, the personal computer **1100** includes a main body portion **1104** including a keyboard **1102** and a display unit **1106** having a display portion **1108**. The display unit **1106** is rotationally movably supported relative to the main body portion **1104** via a hinge structure portion.

In the personal computer **1100**, the physical quantity sensor **100** is incorporated.

FIG. **9** is a perspective view schematically showing a mobile phone (including a PHS) **1200** as an electronic apparatus according to the embodiment.

As shown in FIG. **9**, the mobile phone **1200** includes a plurality of operation buttons **1202**, an earpiece **1204**, and a mouthpiece **1206**. A display portion **1208** is arranged between the operation buttons **1202** and the earpiece **1204**.

In the mobile phone **1200**, the physical quantity sensor **100** is incorporated.

FIG. **10** is a perspective view schematically showing a digital still camera **1300** as an electronic apparatus according to the embodiment. In FIG. **10**, connections with external apparatuses are also shown in a simplified manner.

Here, usual cameras expose a silver halide photographic film with an optical image of a subject, whereas the digital still camera **1300** photoelectrically converts an optical image of a subject with an imaging element such as a CCD (Charge Coupled Device) to generate imaging signals (image signals).

A display portion **1310** is disposed on the back surface of a case (body) **1302** in the digital still camera **1300** and configured to perform display based on imaging signals generated by a CCD. The display portion **1310** functions as a finder that displays a subject as an electronic image.

Moreover, on the front side (the rear side in the drawing) of the case **1302**, a light receiving unit **1304** including an optical lens (imaging optical system) and a CCD is disposed.

When a photographer confirms a subject image displayed on the display portion **1310** and presses down a shutter button **1306**, imaging signals of a CCD at the time are transferred to and stored in a memory **1308**.

Moreover, in the digital still camera **1300**, a video signal output terminal **1312** and a data communication input/output terminal **1314** are disposed on the side surface of the case **1302**. Then, a television monitor **1430** and a personal computer **1440** are connected as necessary to the video signal output terminal **1312** and the data communication input/output terminal **1314**, respectively. Further, the imaging signals stored in the memory **1308** are output to the television monitor **1430** or the personal computer **1440** by a predetermined operation.

In the digital still camera **1300**, the physical quantity sensor **100** is incorporated.

The electronic apparatuses **1100**, **1200**, and **1300** described above include the physical quantity sensor **100** that has a simple configuration and can enhance the detection sensitivity. Therefore, the electronic apparatuses **1100**, **1200**, and **1300** have a simple configuration and can enhance the detection sensitivity.

An electronic apparatus including the physical quantity sensor **100** can be applied to for example, in addition to the personal computer (mobile personal computer) shown in FIG. **8**, the mobile phone shown in FIG. **9**, and the digital still camera shown in FIG. **10**, inkjet ejection apparatuses (for example, inkjet printers), laptop personal computers, television sets, video camcorders, video tape recorders, various kinds of navigation systems, pagers, electronic notebooks (including those with communication function), electronic dictionaries, calculators, electronic gaming machines, word processors, workstations, videophones, surveillance television monitors, electronic binoculars, POS terminals, medical equipment (for example, electronic thermometers, sphygmomanometers, blood glucose meters, electrocardiogram measuring systems, ultrasonic diagnosis apparatuses, and electronic endoscopes), fishfinders, various kinds of measuring instrument, indicators (for example, indicators used in vehicles, aircraft, and ships), flight simulators, and the like.

The invention includes a configuration (for example, a configuration having the same function, method, and result, or a configuration having the same advantage and effect) that is substantially the same as those described in the embodiment. Moreover, the invention includes a configuration in which a non-essential portion of the configurations described in the embodiment is replaced. Moreover, the invention includes a configuration providing the same operational effects as those described in the embodiment, or a configuration capable of achieving the same advantages. Moreover, the invention includes a configuration in which a publicly known technique is added to the configurations described in the embodiment.

The entire disclosure of Japanese Patent Application No. 2012-087244, filed Apr. 6, 2012 is expressly incorporated by reference herein.

What is claimed is:

1. A physical quantity sensor comprising:

a movable body displaceable about a first axis as an axis of rotation and including, with the first axis as a boundary in plan view, a first movable electrode portion disposed in a first region, a second movable electrode portion disposed in a second region, and a damping adjusting portion disposed in the first region or the second region and at an edge portion of the movable body in a direction of a second axis crossing the first axis;

a beam portion supporting the movable body;

a first fixed electrode portion arranged to face the first movable electrode portion; and

a second fixed electrode portion arranged to face the second movable electrode portion, wherein

a first through-hole is disposed in the damping adjusting portion,

each of a plurality of second through-holes is disposed in the first movable electrode portion and the second movable electrode portion,

in a portion excepting the second through-holes in plan view, the area of a region where the first movable electrode portion overlaps with the first fixed electrode portion is the same as the area of a region where the second movable electrode portion overlaps with the second fixed electrode portion,

the first through-hole has a length in a direction of the first axis and a width in a direction of the second axis, the length of the first through-hole being greater than the width of the first through-hole, and each of the plurality of second through-holes has a length in the direction of the first axis and a width in the direction of the second axis, the length of each second through-hole being greater than the width of each second through-hole,

the width of the first through-hole is greater than the width of each of the plurality of second through-holes,

the damping adjusting portion is disposed in both of the first region and the second region, and

the width of the first through-hole of the damping adjusting portion disposed in the first region is greater than the width of the first through-hole of the damping adjusting portion disposed in the second region.

2. The physical quantity sensor according to claim **1**, wherein

the mass of the first region of the movable body and the mass of the second region of the movable body are different from each other.

3. The physical quantity sensor according to claim **1**, wherein

the total area of an opening surface of the second through-hole disposed in the first movable electrode portion, the opening surface being on the first fixed electrode portion side, is the same as the total area of an opening surface of each of the second through-holes disposed in the second movable electrode portion, the opening surface being on the second fixed electrode portion side.

4. An electronic apparatus comprising the physical quantity sensor according to claim **1**,

wherein the electronic apparatus is one of a personal computer, a mobile phone, or a digital still camera.

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